Remarks

It has been noticed, when reviewing the application, that some corruption in the format for the formulas and characters has occurred. Accordingly, pages 6 through 9 have been revised to have the proper elements clearly set forth.

Examination of the application on its merits is awaited.

Respectfully submitted,

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William M. Lee, Jr.
Registration No. 26,935

Lee, Mann, Smith, McWilliams, Sweeney
& Ohlson
P.O. Box 2786
Chicago, Illinois 60690-2786
(312) 368-1300 Telephone
(312) 368-0034 Facsimile

VERSION WITH MARKINGS TO SHOW CHANGES MADE

In general, a control system tries to hold the output level of the system at that specified set point.

The system achieves this by increasing or decreasing, for example, an intermediate variable in a feed back loop.

If there are multiple components sharing the output, all those components get treated in an even manner, in a general case.

In the network operator/user-aggregate scenario, this is equivalent to:

The operator wants to set a control level for each class of traffic such that isolation between classes are maintained.

The operator would wish that the control level kept is maintained, in other words the given supply is fully consumed.

The intermediate variable is manipulated according to the difference between the supply and how much it is consumed (in other words the demand). This variable is usually termed as the resource price. This resource price works as a forcing function that drives an economic system.

There are always multiple user-aggregates sharing the resource and an even treatment to all of them ensures a particular form of fairness known as proportional fairness.

The general construction of the exemplary system is shown in Figure 1. A more specific example with multiple resources and users will be described below. In Figure 1, the parameters are defined as follows;

[Ck] $\underline{C_k}$:	Set point for control, resource unit
[Ek] $\underline{E_k}$:	Difference variable
k :	Sample step number
[Kk] $\underline{K_k}$:	Gain parameter

[Pk] $\underline{P_k}$: Resource price, price unit for resource unit

[PPk] $\underline{PP_k}$: Potential willingness to Pay by the user, Potential willingness to pay unit

[Yk] $\underline{Y_k}$: Output level, resource unit

(Notes: (1) [Ck] $\underline{C_k}$, [Kk] $\underline{K_k}$, [PPk] $\underline{PP_k}$ etc need not vary for sample steps. (2) The resource price unit could be expressed as price unit per unit resource if the resource price is divided by the resource capacity. But then again this has to be rectified later in the ensuing calculations. Hence this is avoided.).

The difference between the set point and controlled output is given by

[Ek = Ck – Yk] $\underline{E_k = C_k - Y_k}$

This difference is multiplied by a gain factor and fed to the resource pricing block. As the consumption of resource increases, the resource price must go higher and vice versa.

Hence this gain-difference product is given as a negative input to the pricing block. The resource price is later used as the denominator for calculating resource consumption. Here it works, for example, as the price to use a common facility (The numerator is the potential willingness to pay).

An initial resource price condition (P0) is forced on the system and is taken as unity. The resource price is also bounded to upper and lower limits so as to define an operating regime.

The output of the pricing block is given by

[Pk+1 = Pk – KkEk]$\underline{P_k+1 = P_k - K_kE_k}$

The output level Yk is now calculated as

[Yk+1 = PPk+1 / Pk+1] $\underline{Y_{k+1} = PP_{k+1} / P_{k+1}}$

This is now fed back for sustained operation.

Multiple resources and user aggregates using different paths:

This is the usual scenario.

Let the total number of resources be RT and the total number of user aggregates be NT (active paths). Then the parameters of interest modifies to incorporate the different sets of resources, user aggregates and paths:

[CRk] C_{Rk} : Set point for control for resource R

[ERk] E_{Rk} : Difference variable for resource R

[KRk] K_{Rk} : Gain parameter for resource R

[NT] N_T : Number of user aggregates (active paths)

[PNk] P_{Nk} : Total resource price for user aggregate N

[PRk] P_{Rk} : Resource price for resource R

[RT] R_T : Number of resources

[UN] U_N : Resource consumption by user aggregate N (eg. Flow rate of active path)

[VT] V_T: Number of paths (or combinations)

[PPNk] PP_{Nk} : Potential willingness to Pay by the user aggregate N

[YRk] Y_{Rk} : Output level of resource R

[RN] R_N : Resource subset used by user aggregate N

[NR] N_R : User aggregate using resource subset R

The equations become:

[ERk = CRk – YRk] $E_{Rk} = C_{Rk} - Y_{Rk}$

[PRk+1 = PRk – KRkERk] $P_{Rk+1} = P_{Rk} - K_{Rk}E_{Rk}$

If there are [NT] N_T user aggregates using these resources in [VT] V_T paths the resource price for each user aggregate is calculated as:

[PNk+1 = □ PRk+1,R □ RN] $P_{Nk+1} = \Sigma P_{Rk+1},\ R \in R_N$

The resource consumed by user aggregate N is given by:

[UNk+1 = PPNk+1 / PNk+1] $U_{Nk+1} = PP_{Nk+1} / P_{Nk+1}$

The output level is now given as:

[Yrk+1 = □ UNk+1, N □ NR] $Y_{Rk+1} = \Sigma U_{Nk+1},\ N \in N_R$

This summation is an automatic result of resource consumption by different users. This value is now fed back for sustained operation.

Scalability: This suggests that the system above is scalable to multiple layers of hierarchies.

Multiple users contributing to a user aggregate:

This subsection is included for completeness.

[NT] N_T : Total number of user aggregates

[PNk] P_{Nk} : Total resource price for user aggregate N

[UN] $\underline{U_N}$: Resource consumption by user aggregate N

[VT] $\underline{V_T}$: Total number of paths

[PPNk] $\underline{PP_{Nk}}$: Potential willingness to Pay by the user aggregate N

n : Number of users making N user aggregates

[Pnk] $\underline{P_{nk}}$: Price for individual user making up total aggregate resource price PNk

[Un] $\underline{u_n}$: User resource consumption making up aggregate consumption UN

v : Number of individual paths making V aggregate paths

[PPnk] $\underline{PP_{nk}}$: Potential willingness to Pay by user making up aggregate PPNk

[N □ n] $\underline{N \in n}$

[PNk = □ Pnk] $\underline{P_{Nk} = \Sigma P_{nk}}$

[UN □ un] $\underline{U_N \in u_n}$

[V □ v] $\underline{V \in v}$

[PPNk = □ PPnk] $\underline{PP_{Nk} = \Sigma PP_{nk}}$

The operation at this level is mainly decided by the business policy. It may be defined by how individual SLAs are made, how the utilities are assessed and distributed and/or how the individuals are charged.

[PNk] $\underline{P_{Nk}}$ and [PPNk} $\underline{PP_{Nk}}$ are parameters in the carrier network level for user aggregates. How these are distributed and mapped to the real world customer relations/economics is a subject matter not dealt in this paper. It could be a linear or non-linear relationship as decided by various policies.

An implementation of the principles outlined has been performed on a real network. This used a cluster of Linux routers and a set of distributed flows. The model for demonstration uses three ingress routers, two core routers and four traffic sources for generating flows and for introducing disturbance to the network. The model uses a distributed three flows scheme.

This model is sufficient to demonstrate the principles and allows the study of interactions between the three component flows.

The lab model for implementation was devised to be compliant with the COPS (Common Open Policy Server) Resource Broker model as shown:

The user policies to be implemented are stored in the Policy Information Base (PIB). The implementation decisions are made at the Policy Decision Point (PDP). These policies are then enforced at the Policy Enforcement Points (PEP). The network topology and measurement information is stored and collected at the Network